MICROCOPY RESOLUTION TEST CHART

AD-A175 534

Multipoint Auger Depth Profiling System

G. W. STUPIAN and M. S. LEUNG
Chemistry and Physics Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, CA 90245

15 May 1986

DTIC
ELECTE
DEC 3 0 1986
D

DTIC FILE COPY

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SD-TR-86-07	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* MULTIPOINT AUGER DEPTH PROFILING SYSTEM		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER TR-0086(6417-01)-1
7. AUTHOR(*s*) Gary W. Stupian and Martin S. Leung		8. CONTRACT OR GRANT NUMBER(*s*) F04701-85-C-0086
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Aerospace Corporation El Segundo, CA 90245		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Space Division Los Angeles Air Force Station Los Angeles, CA 90009-2960		12. REPORT DATE 15 May 1986
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(*If different from Controlling Office*)		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Auger Electron Spectroscopy
Depth Profiling

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A computer-based control system for the scanning Auger microprobe (SAM) is described that greatly enhances laboratory capabilities to characterize microelectronic devices. Programs under way are designed to improve the reliability of gallium arsenide field effect transistors through a study of degradation resulting from diffusion of contact metallization. These studies depend on determining elemental compositions as a function of depth

DD FORM 1473
(FACSIMILE)

19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

.(depth profiling) in various regions of devices after the devices are
subjected to electrical and thermal stress. The SAM data handling system
cannot process data originating at more than one point. This constraint
severely limits the depth profiling capability of the SAM as applied to
microelectronic devices. Laboratory personnel have developed a computerized
control system to depth profile a specimen at a number of different points
simultaneously. This capability will provide information on the
distribution of chemical elements in three dimensions needed to study device
degradation. Data illustrating the capability of the computerized profiling
system are presented.

CONTENTS

FIGURES

DTIC
COPY
INSPECTED

I. INTRODUCTION

Gallium arsenide field effect transistors (GaAs FETs) are being used to replace traveling wave tubes on Space Division spacecraft, but their long-term reliability has yet to be validated. The dimensions of features of interest (e.g., the gate widths) on power microwave GaAs FETs are on the order of 1 μm or less. The devices typically operate at junction temperatures of 200°C and are intended for use in systems with 10-year on-orbit lifetimes. Under these conditions, interdiffusion and electromigration of metal contacts are likely to be life-limiting processes. Programs aimed at investigating GaAs FET reliability, and diffusion processes in particular, are under way in our laboratory.

The reliability of GaAs FETs is a prime example of a problem whose solution requires a knowledge of the distribution of chemical elements in three dimensions, i.e., both along a specimen surface and perpendicular to a surface. In the particular case of GaAs FETs, diffusion processes are being investigated by obtaining three-dimensional depth profiles in different regions (multipoint depth profiling) of the device after subjecting test devices to various electrical and thermal stresses.

In principle, the scanning Auger microprobe (SAM) is one of the most valuable analytical instruments for obtaining elemental distributions in three dimensions. In practice, the available SAM can realistically make depth profile measurements only at one point at a time on a specimen surface. Without a multipoint depth profiling capability, the utility of the SAM for device analysis is severely limited. In this report, we describe the integration of the SAM with a Z80-A based microprocessor to permit multipoint depth profiling. The system incorporates other desirable features such as disk storage of data and data manipulation capabilities. This system increases the laboratory's capability to analyze GaAs FETs in addition to integrated microelectronic circuits.

II. BACKGROUND

The Aerospace Corporation Chemistry and Physics Laboratory (CPL) has a
Perkin Elmer/Physical Electronics Model 590 SAM that provides elemental analy-
ses of specimens with a lateral resolution (i.e., along the specimen surface)
on the order of 1 µm or less. A key component of the SAM is an electron gun
that produces a focused electron beam with a minimum diameter of 0.2 µm.
Elemental analysis is made possible by analyzing the Auger electrons emitted
from the specimen surface. In the Auger process, a deep core electron is
ejected by the incident electron beam, leaving the atom ionized and in a
highly excited state. An outer shell electron makes a level transition to
fill the hole left behind by the ejected electron. The excess energy produced
by the outer to inner level transition causes a third electron, the Auger
electron, to be emitted with an energy determined almost entirely by the
energy levels of the emitting atom (Fig. 1). Thus the Auger electrons emitted
from the specimen are characteristic of the emitting species, and qualitative
and quantitative analyses are possible through energy analysis of the emitted
electrons. A typical Auger spectrum obtained with the SAM electron energy
analyzer is shown in Fig. 2. The Auger peaks typically have both a positive
and negative maximum about the baseline as a consequence of the electronic
signal differentiation usually employed in the detection process. The ele-
ments present in the specimen are identified by the energies of Auger peaks in
the electron spectrum, whereas quantitative information is obtained from the
peak-to-peak signal amplitudes.

The Auger electrons of interest for elemental analysis typically have
kinetic energies between 20 and 200 eV. These Auger electrons can travel only
a limited distance before undergoing a collision with other electrons and
blending into the general secondary electron background. Therefore only ele-
ments in the outer three or four atomic layers of the specimen surface are
detectable. In order to obtain elemental concentrations as a function of
depth, ion etching is employed to remove surface material continuously at a

rate of 10-300 A/min while Auger analysis is being carried out simulta-
neously. The amplitudes of the Auger peaks are recorded as a function of time
(equivalent to depth, if the sputter rate is known); thus an elemental depth
profile is obtained.

Unfortunately, the sputter ion gun in the SAM produces an ion beam about
1 to 2 mm in diameter. When a microelectronic device is ion etched, its
entire surface must be sputtered because the size of the ion beam exceeds the
size of the device. In order to properly characterize a device, elemental
depth profiles in several regions of the device are usually required.
Although the SAM control system can store the coordinates of up to 20 pre-
selected points, its standard analog data handling circuitry simply cannot
process a data stream corresponding to many different elements at several
different points. The solution to this data handling problem is to use a
microprocessor.
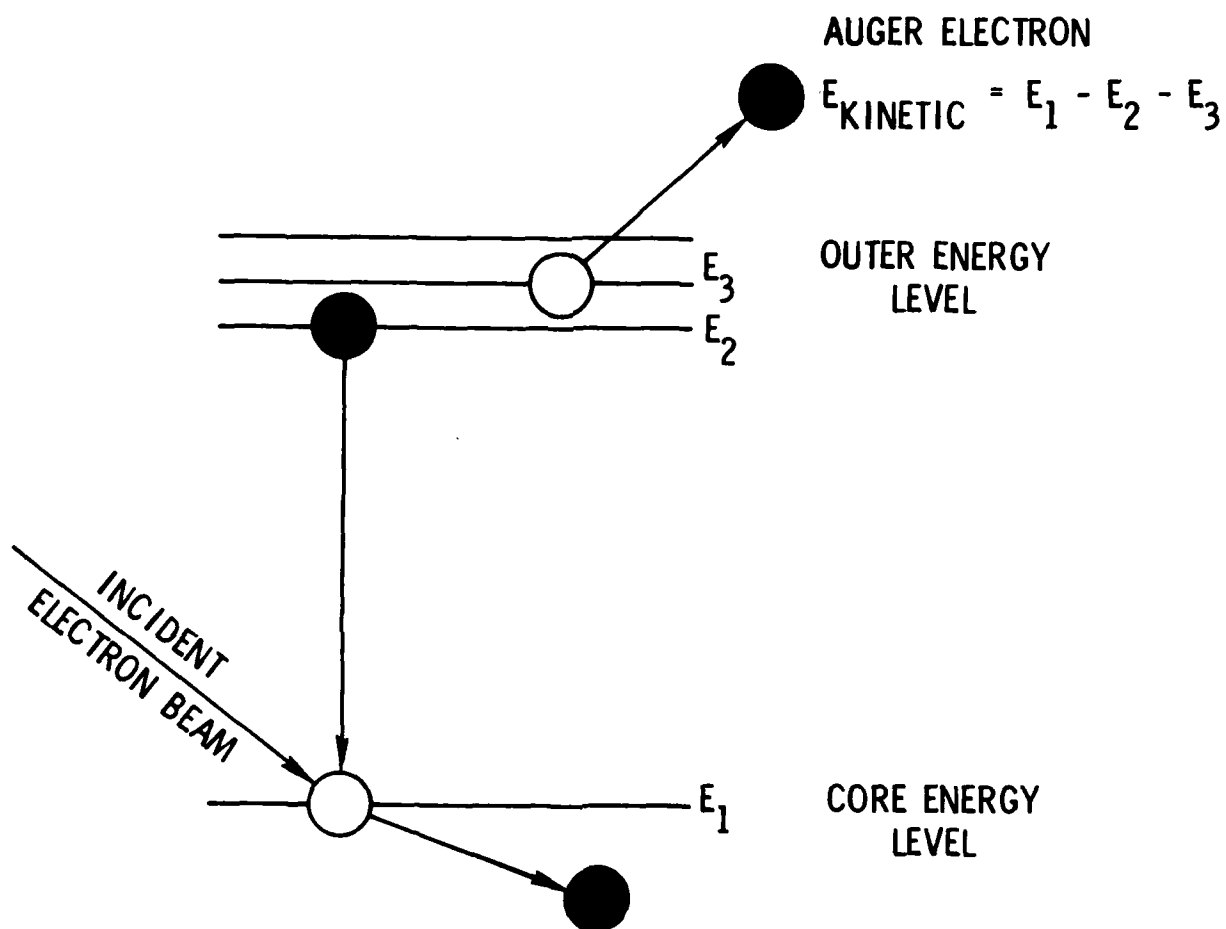
AUGER ELECTRON

$$E_{KINETIC} = E_1 - E_2 - E_3$$

OUTER ENERGY LEVEL

E_3

E_2

INCIDENT ELECTRON BEAM

E_1 CORE ENERGY LEVEL

Fig. 1. The Auger process. The electronic rearrangement resulting in Auger emission is illustrated.

7

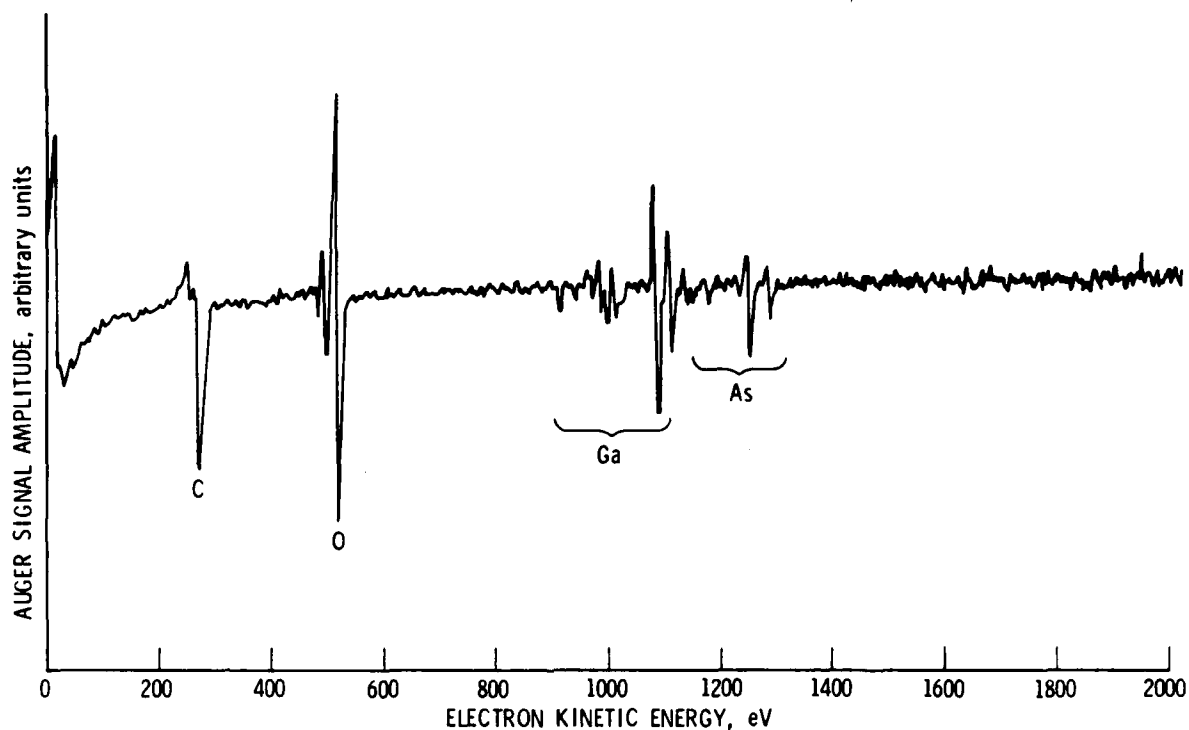Fig. 2. A typical (derivative) Auger spectrum obtained from the substrate surface of a 1/4-W MSC GaAs FET. In addition to gallium and arsenic, oxygen and carbon are also detected. The GaAs surface is always covered by a thin surface oxide. Carbon is a common surface contaminant and is also almost always present on the surface of a device. The carbon and oxygen peaks vanish almost immediately when ion sputtering is initiated.

8

III. CPL COMPUTERIZED AUGER CONTROL SYSTEM

The CPL Auger control system was basically designed to permit multielement and multipoint depth profile analyses to be obtained with the available SAM. Permanent disk data storage was also considered essential. The system controls the electron energy analyzer and digitizes and stores the Auger data. The electron beam is stepped sequentially between preselected points on the specimen surface. At each point, the electron kinetic energy ranges corresponding to the different elements of interest are scanned. The Auger peak-to-peak amplitude for each element at each point, along with other necessary information such as the elapsed time, are stored on disk. The data are plotted with the use of a separate microprocessor equipped with a high resolution graphics printer. Further system details are presented in the Appendix.

IV. RESULTS AND DISCUSSION

The capabilities of the system are illustrated by results obtained on a microwave GaAs FET (Microwave Semiconductor Corporation (MSC) 1/4-W device). An electron micrograph obtained with the SAM (Fig. 3) exhibits the general features of this particular device.

A depth profile obtained in the drain region is presented in Fig. 4. A depth profile represents a cross-sectional view of the elemental composition of the device. Each continuous line on a depth profile plot represents the Auger signal intensity of an element (proportional to its concentration) as a function of time. The time scale is equivalent to a depth scale for a known sputtering rate. Both the sputter rate and the relationship between measured Auger signal intensities and elemental concentrations are, in general, sample-dependent. More quantitative results may be obtained, if needed, through the use of appropriate standards. The measured depth profile in the MSC GaAs FET reveals just the layered structure specified by the manufacturer for this particular unstressed device (Fig. 5). The various layers in this complex metallization sequence are well resolved.

This new capability for multipoint depth profile analysis is ideally suited to the investigation of diffusion degradation mechanisms in GaAs FETs. The metallization layers in unstressed devices are well defined, with sharp boundaries. The layer boundaries in devices subjected to various levels of electrical and thermal stress will appear less distinct because of inter-diffusion. Interpenetration and segregation of constituents may lead to substantial modification of the original structure. The composition changes revealed by Auger depth profiling will be interpreted in terms of a diffusion model and will be correlated with device performance.
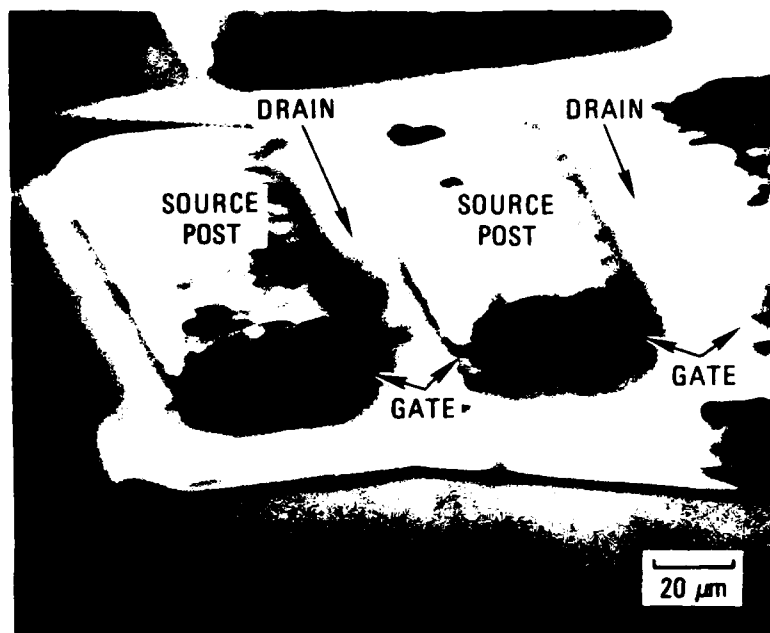
11

Fig. 3. A secondary electron micrograph of the test device (MSC 1/4-W GaAs FET). This device is of the "flip chip" type and is shown here after being removed from its mounting pedestal to expose the metallization. The prominent raised areas are the plated source posts. The drain metallization is visible in the foreground, whereas the gates are discernible as narrow cracks between the source and drain regions.
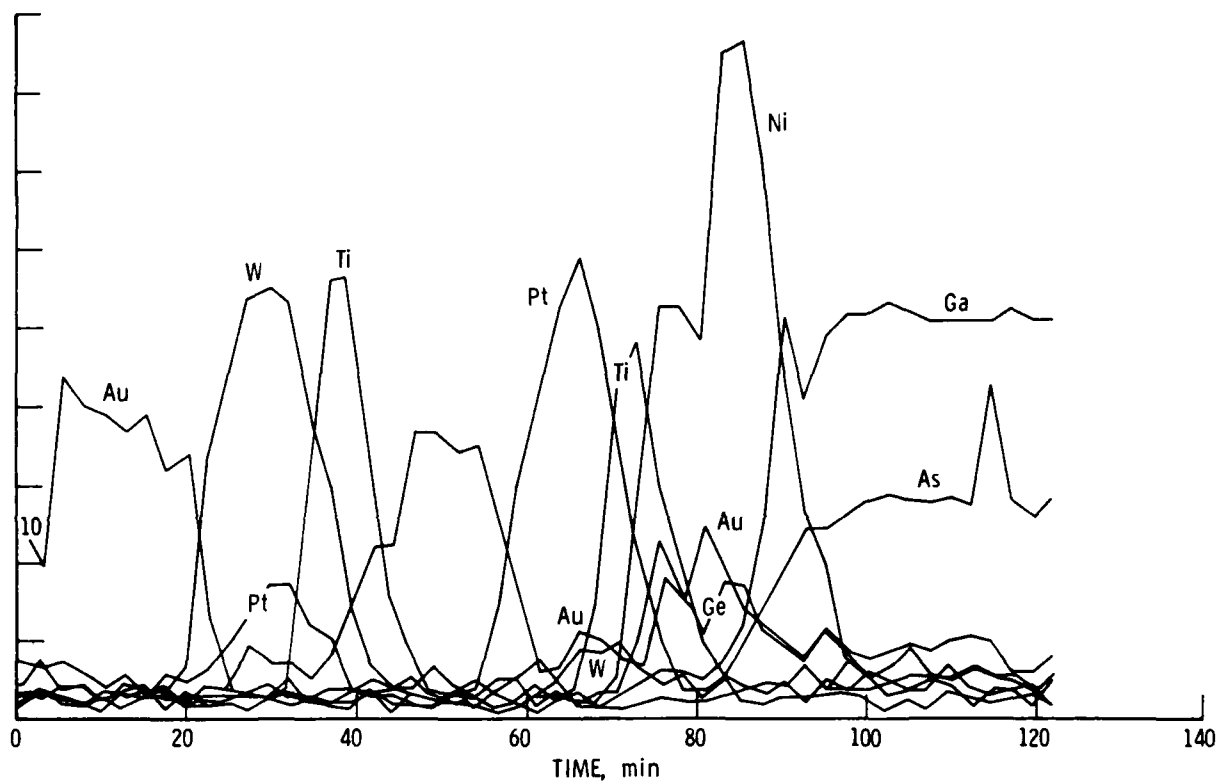
Fig. 4. Depth profile in drain region of test device. Ten elements were profiled at three points in this particular experimental run. The carbon and oxygen profiles were not printed in this figure because the concentration of these elements fell very rapidly to zero.
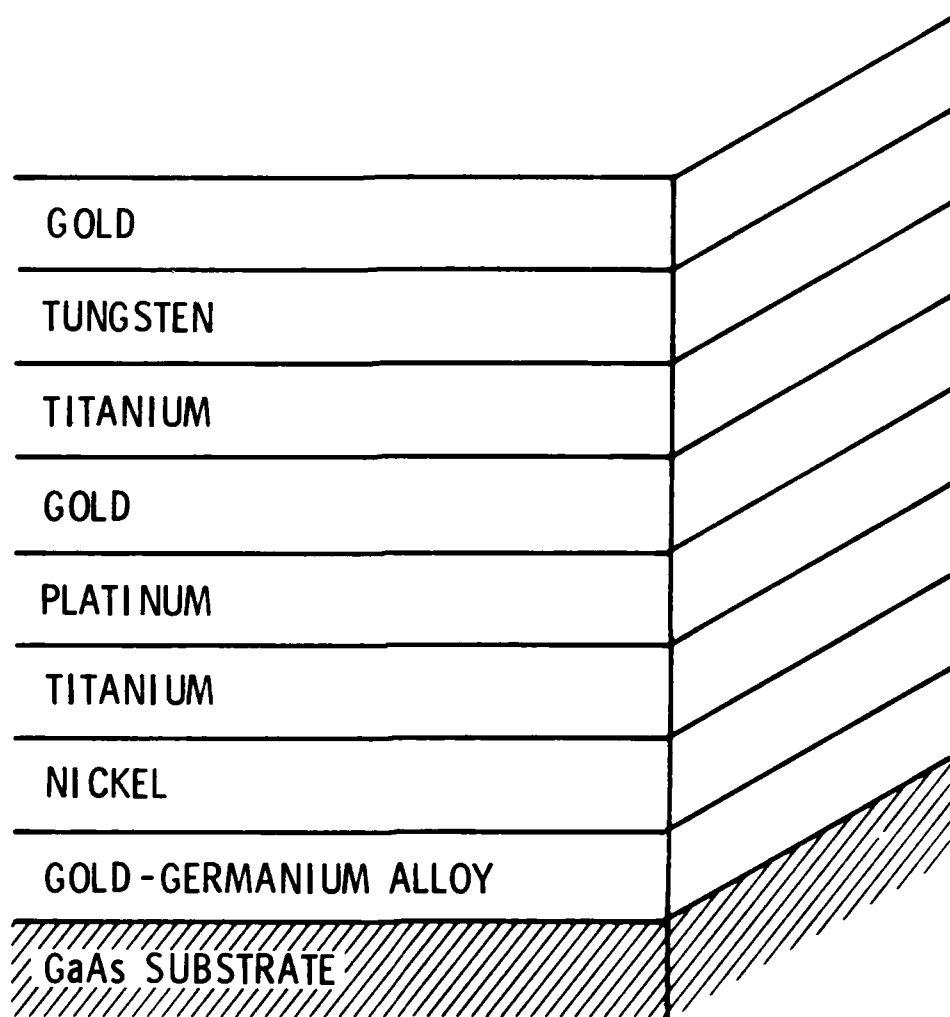
13

Fig. 5. Drain metallization sequence in test device as obtained from manufacturer. This diagram is schematic only. Layer thicknesses are not shown to scale.

APPENDIX

A more detailed discussion of the hardware and software constituting the Auger multipoint depth profiling system is presented in this Appendix.

A. CONTROL SYSTEM IMPLEMENTATION

1. HARDWARE

The system is based on a Cromemco Z80A microprocessor system that has the popular S100 bus structure. Analog-to-digital and digital-to-analog converters, a system clock, and various peripheral control cards that plug into the bus were available in the laboratory. A block diagram of the control system is shown in Fig. A-1.

The SAM analyzer sweep supply is controlled by a 16-bit digital-to-analog converter (DAC) that drives an analog input on the analyzer supply. The Auger signal amplitudes are digitized by a 12-bit analog-to-digital converter (ADC). A graphics output board generates various high resolution data displays during system operation. One-bit logic level signals from the computer are used to step the SAM electron beam between selected points and to turn the ion gun on and off.

2. SOFTWARE

The Auger control program is written entirely in the BASIC language (Cromemco 32K structured basic). The program is intended to be "friendly" to the user. The SAM operator is guided step by step by prompting questions when using the program. The number of points and the energy ranges corresponding to the desired elements are entered first. The gain of each of these data channels may also be specified independently, and in fact the gain of a channel will be reduced automatically if the signal amplitude approaches the range limits of the data ADC. After a scan energy range is defined, a display of the ADC output over that energy range is presented to the operator on the video monitor. The operator is then given an opportunity to alter the energy and gain parameters if desired. After all of the energy ranges have been defined, the system clock is initialized, and the system begins scanning the
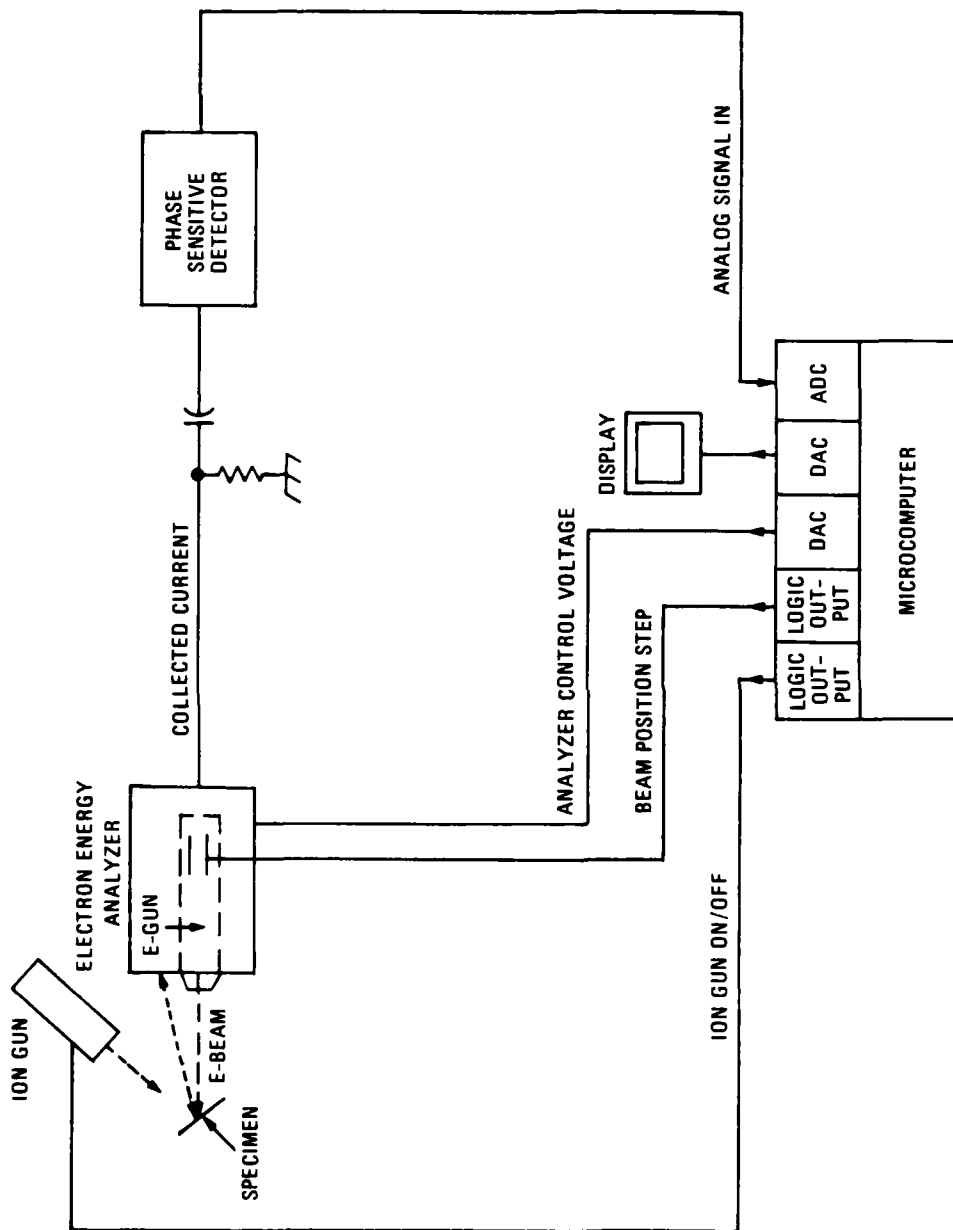
15

Fig. A-1. Block diagram of Auger control system. The electron gun is mounted coaxially within the two cylinders constituting the electron energy analyzer (cylindrical mirror type). The structure of the analyzer is not shown in detail because this diagram is intended to illustrate computer control functions.

energy channels in order at each point, starting at point 1. The SAM beam is then positioned at point 2, and the process is repeated. After scanning all of the established energy ranges at each defined point, the system returns the electron beam to point 1 and repeats the process. For each energy channel, the peak-to-peak signal amplitude, the ADC gain, the energies at which the signal maxima and minima occurred, and the time at which the scan was made are all automatically stored on a floppy disk along with the data channel and point numbers.

The ion gun is controlled through the computer console. The time at which sputtering is initiated is also stored on the disk. Data collection may be interrupted and resumed at any time so that full Auger scans may be made at different points in the sputtering process to provide complete elemental analyses.

3. DATA PLOTTING SYSTEM

Data are plotted using a separate Cromemco computer equipped with an Anadex graphics printer. Data may first be viewed on a video monitor for preliminary evaluation. Several plotting options are available. The concentrations of all elements at a single point may be displayed, as may the concentrations of a single element at all defined spatial points. The energy of the minimum of the signal amplitude for a particular channel at a selected point may also be plotted. Auger peak energy plots are useful to check for slight changes in Auger peak positions that sometimes occur when the chemical state of an element changes (e.g., elemental silicon versus silicon in SiO_2). It is also possible that an Auger peak of an element other than the one expected may appear in an energy window. The energy plot mode will reveal such interferences.

17

END

2-87

DTIC